

Wind Erosion Modelling in a Sahelian Environment

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Introduction

On a field scale, observations of wind-blown sediment transport often show a considerable spatial variation caused by differences in soil characteristics, surface roughness, topography, vegetation and soil crusting. In practice it is almost impossible to measure all factors that explain the variation in observed sediment transport. If we add the fact that fields of farmers in a sahelian environment are more heterogeneous in soil management, living and dead vegetation cover and application of fertilizer than the average fields of "western" farmers, we can expect considerable variation in erosion and deposition of sediment due to wind-blown mass transport in a sahelian field.

In the sahel soil conservation tools are limited, it is important to warily manage them. A good simulation model, which correctly predicts erosion and deposition at the field scale, will be a useful tool in successful application of soil conservation measures.

In this article we discuss three modelling approaches and their performance in the Sahel. Field data of wind erosion measurements in northern Burkina Faso are used to run a geo-statistical (spatial modelling), an empirical (RWEQ) and a deterministic (WEPS) model, in order to determine which model predicts best the spatial variability in wind blown mass transport in the Sahel. Results of the different modelling approaches will be discussed.

Materials and methods

During the early rain season of 2001, field data of 12 wind erosion events were collected at 3 sites with different geomorphologic settings; a degraded site, a valley and a dune, in northern Burkina Faso. Each site of 80 x 80 m. is instrumented with 17 Modified Wilson and Cook catchers. The catchers are regularly distributed so that in each wind direction a line of 5 catchers is formed. In one line each of the catchers are 15 m. apart. At the dune and the degraded zone weather stations were installed. Since field in the valley floor was situated less then 500 m from the degraded zone, weather data of the degraded zone was also used for the valley floor. Wind speed and wind direction were measured every one-minute at a height of 2 m. At the degraded site a wind profile is continuously measured at 0.5, 1, 2 and 3 m. Mass transport was determined by sampling over 5 heights and intergrating over the height.

The Revised Soil Erosion Equation (RWEQ)

The Revised Soil Erosion Equation (RWEQ) uses a number of input factors to estimate transport capacity, critical field length and field soil loss. The wind factor (WF), erodible fraction (EF), surface crust factor (SCF), roughness (K') and crop on the ground factor (COG) were determined for each erosion event. For further details about the procedure to determine these values we refer to Fryrear et al (1998a and 1998b). The WF for each storm was computed from one-minute wind measurements, EF was calculated as a function of percent sand, silt, clay organic matter and calcium carbonate content (Fryrear et al., 1998). SCF was defined as a function of percent clay and organic matter content (Fryrear et al. 1998). K' was determined using measured roughness parameters and COG was estimated using the amount of flat and standing residue (Fryrear et al., 1998). In the dry period the input parameters were determined once a month and in the wet period these parameters were determined once a week.

In RWEQ equations 1 and 2 are used to estimate maximum sediment transport (Q_{max}) and critical field length (S).

$$Q_{max} = 109.8(*WF * EF * SCF * K' * COG) \quad (1)$$

$$S = 150.7(WF * EF * SCF * K' * COG)^{-0.371} \quad (2)$$

Finally we used equation 3 to determine mass transport at a certain distance downwind.

$$Q(x) = Q_{max}[1 - e^{-\frac{x^2}{S^2}}] \quad (3)$$

Maximum sediment transport (Q_{max}) and critical field length (S) can be calculated from the field measured data by performing least squares non-linear regression using equation 3.

The Wind Erosion Prediction Project (WEPS)

The WEPS erosion sub-model decides if erosion can occur based on the current soil surface roughness (oriented and random), flat and standing biomass, aggregate size distribution, crust and rock cover, loose erodible material on the crust and the soil surface wetness (Hagen, 1995). The aerodynamic roughness (z_0) is calculated using information about ridge and random roughness and vegetation characteristics. The friction velocity (u_*) using eq (4).

$$u_* = \frac{0.4 * U}{\ln\left(\frac{z}{z_0}\right)} \quad (4)$$

In which U is the wind speed at height (z), 0.4 is the von Kármán constant and z_0 is the aerodynamic roughness. Since the friction velocity is the driving force behind the model, it is very important to correctly predict this parameter.

At the degraded site we measured wind speed at 0.5, 1, 2 and 3 m. The universal velocity distribution eq. 5 was used to determine the friction velocity and the aerodynamic roughness for each storm at the degraded site..

$$U = u_* 0.4 \ln\left(\frac{z}{z_0}\right) \quad (5)$$

The observed friction velocity and aerodynamic roughness are compared to the values predicted by WEPS.

The spatial modelling approach

Due to the fact that it is almost impossible to measure the distribution of all factors that account for the spatial variation in sediment transport, Sterk and Stein, 1997 suggest an alternative modelling approach for sediment transport modelling. By making use of geostatistics they produced storm-based maps of sediment transport.

In geostatistics the variogram is used to model the spatial variability. A common rule is that at least 30-50 measurements are needed to obtain representative variograms. As we have only 17 measurements per storm, we decided to combine the measurements of all storms in one overall variogram per site. We could do this by first standardising the sediment transport values (standardised = [value-mean]/variance), as a strong relation exists between mean and variance of the measurements of each storm. The variogram was modelled using a spherical model with a nugget effect. This model was tested using cross-validation. During cross-validation the variogram model is used to re-predict actual observations from neighbouring observations. With a perfect variogram the mean cross-validation Z-score should be 0, with a standard deviation of 1. To obtain spatial maps per storm that honor the high variability at close distances in the field, we used the overall variogram model in conditional stochastic simulation. The geostatistical variography and model were carried out with the geostatistical software package GSTAT (www.gstat.org).

Results and Discussion

RWEQ

Fig. 1 is an example plot of soil losses across a field with a critical field length (s) of 50 m. The RWEQ -model assumes a non-eroding boundary around a field, based on this assumptions highest soil losses will be predicted in the zone near the non-eroding boundary.

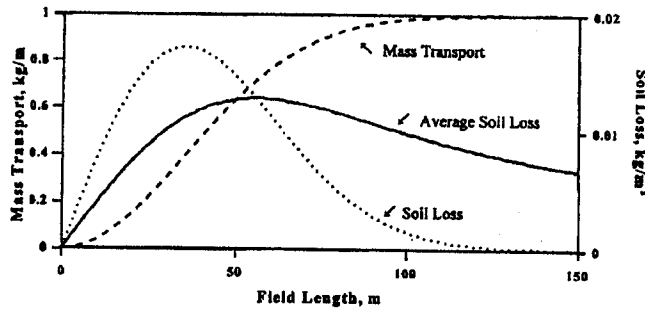


Fig1) Relationship between mass transport, soil loss and average soil loss from RWEQ using $s=50$ m and $Q_{max}=1.0$ kg/m. (Fryrear et al, 1998)

In the Sahel the fields are not surrounded by a non-eroding boundary. The edges of the fields are often indicated by a single tree, a path or a large rock. None of our research sites had a non-eroding boundary, so we do not know at which point in the predicted plot the measurement were made. Therefore it is virtually impossible to compare observed soil transport with soil transport predicted by the model as it is. Preliminary results show that it is possible to transpose the plot over a distance α using equation 5.

$$Q(x) = Q_{max} [1 - e^{-\frac{(x+\alpha)^2}{s^2}}] \quad (5)$$

With this formula the plot will cross the Y-axis at point (0, Q) (the first field measurement) and cross the x-axis at point $(-\alpha, 0)$. By performing least squares non-linear regression analysis using equation 5, a good estimation for Q_{max} and S can be obtained. Only now the observed data can be compared with the predicted data.

WEPS

The degraded site is a completely bare area with an extremely smooth surface ($RR=1.21$). Since no vegetation is present and the area is not cultivated (no oriented roughness) the aerodynamic roughness is only determined by the random roughness.

The meteostation was situated in such a way that winds coming from the direction North-West till East had a free run without obstacles. Table 1 shows average wind speed of the storm and the observed and predicted u_* and z_0 .

Table 1 Average wind speed of the 2001 storms and the observed and predicted u_* and z_0 for the degraded site.

Date	U (m/s)	WEPS z_0 (mm)	WEPS u_* (m/s)	Obs z_0 (mm)	Obs u_* (m/s)
22-5-01	8.64	0.363	0.395	4.40	0.823
3-6-01	7.17	0.363	0.327	6.25	0.903
9-6-01	8.80	0.363	0.402	2.17	0.880
19-6-01	8.52	0.363	0.388	6.72	0.783
22-6-01	9.21	0.363	0.420	6.90	0.750
29-6-01	7.49	0.363	0.341	6.25	0.861
11-7-01	8.40	0.363	0.383	4.07	0.854
13-7-01	8.19	0.363	0.374	5.19	0.837

In general, WEPS predicts the aerodynamic roughness a factor 10-20 too low and the predicted friction velocity is half of the measured friction velocity. Apparently the aerodynamic roughness at smooth bare surfaces is not only determined by the random roughness. Due to the too low prediction of the aerodynamic roughness the prediction of the friction velocity is low. Therefore further investigation on the behaviour of wind profiles on these kind of smooth surfaces is necessary. WEPS can not simply be applied for smooth soil surfaces in the Sahel. We suggest to add a formula that better predicts the aerodynamic roughness for smooth surfaces in the Sahel.

The spatial modelling approach

The model parameters of the overall variogram model and the cross-validation can be found in table 2. The valley variogram showed only noise, so no spherical model could be fitted. Comparing the parameters of the dune and degraded site, it is clear that the nugget to sill ratio is very high, indicating a large contribution of short distance variability for both sites.

Table 2) Parameters of the spherical variogram model and results of the cross validation

Site	Co	C	A	Total Mean Z	Total St-dev Z
Degraded site	0.40	0.76	63.81	0.07	0.91
Dune	0.40	0.7	24.46	0.13	0.84
Valley	0.62			0.16	0.75

Co=nugget constant, C=sill parameter, a=range parameter

Further, the range value for the degraded site is much larger than the range value for the dune site, indicating that the variability pattern is over larger distances for the degraded site than for the dune site. This can easily be explained by lack of residue cover, the more even crusting pattern and the lack of vegetation at the degraded site.

The cross validation of the variogram of the degraded site was ok, but for the valley and dune site the cross validation is less well. The only way to obtain better variograms, is to carry out more measurements per storm. Unfortunately, sampling at a density sufficient for variogram modelling cannot not be done in wind erosion studies, because of the high cost of equipment and labour and because such a high density of catchers will probably alternate the wind field and no realistic pattern of erosion and deposition will be measured.

Therefore, despite the weak variograms, we performed conditional stochastic simulation with these variograms to obtain mass transport maps at the three sites for all 12 storms. The produced maps emphasise the strong variations in mass transport across short distances. Based on this, it can be stated that, in Sahelian regions, it will be more useful to distinguish erosion and deposition areas in the field than to describe soil loss per unit area, as is traditionally done. Windblown sediment transport is highly controlled by vegetation cover and soil crusting. These factors are not evenly distributed over the sites of the dune and the valley, whereas the degraded site is more or less homogeneous for these factors. We expect that if we combine the map of the conditional stochastic simulation with maps of the spatial distribution of soil crusting and vegetation cover, we will have enough information about the possible spatial variation of erosion and deposition for better application of soil conservation measures.

References

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